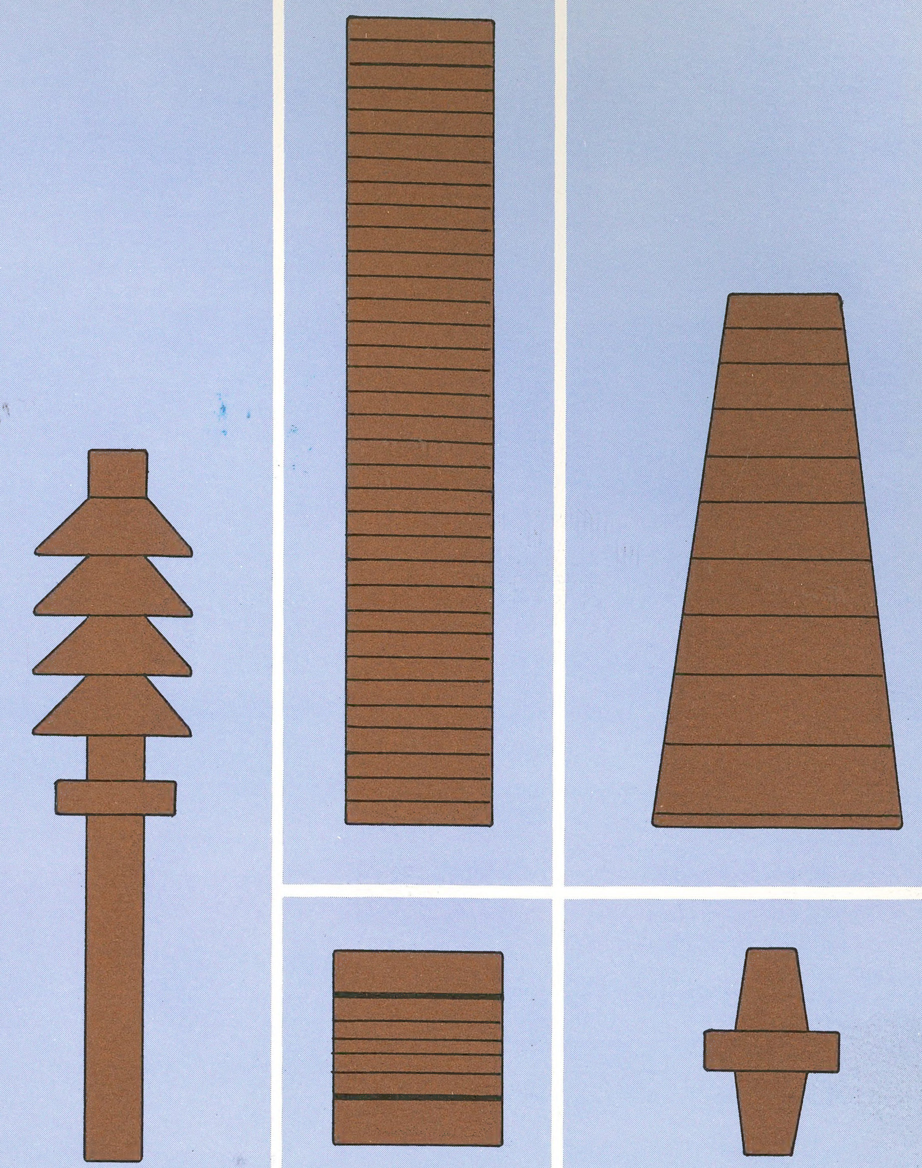
GENERAL ELECTRIC CO.
INSULATOR DEPARTMENT
2525 INSULATOR DRIVE
BALTIMORE, MD. 21230

TIA-204 (1500) 6-66

LITHO IN U.S.A.



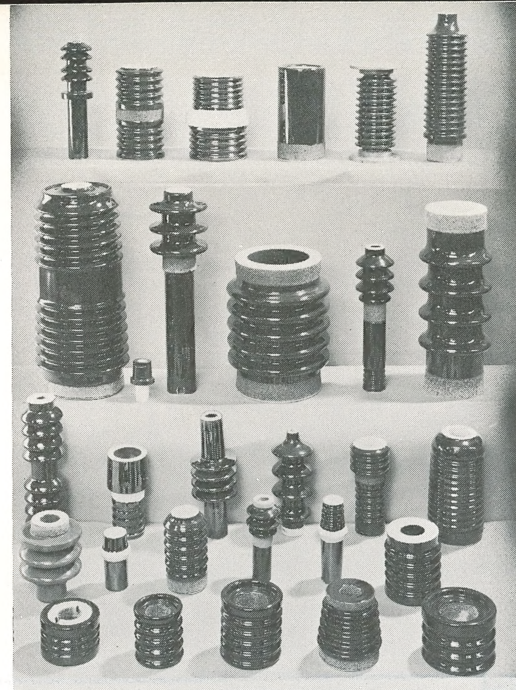
Designing apparatus porcelain

Designing apparatus porcelain

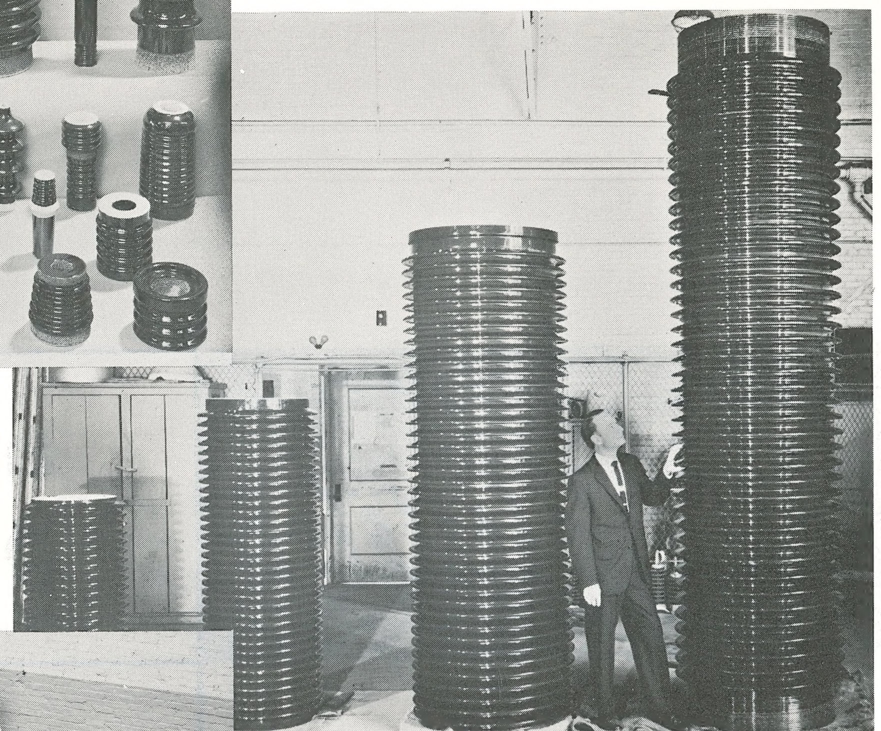
from

Insulator Department
General Electric Company
2525 Insulator Drive
Baltimore, Maryland 21230

June, 1966

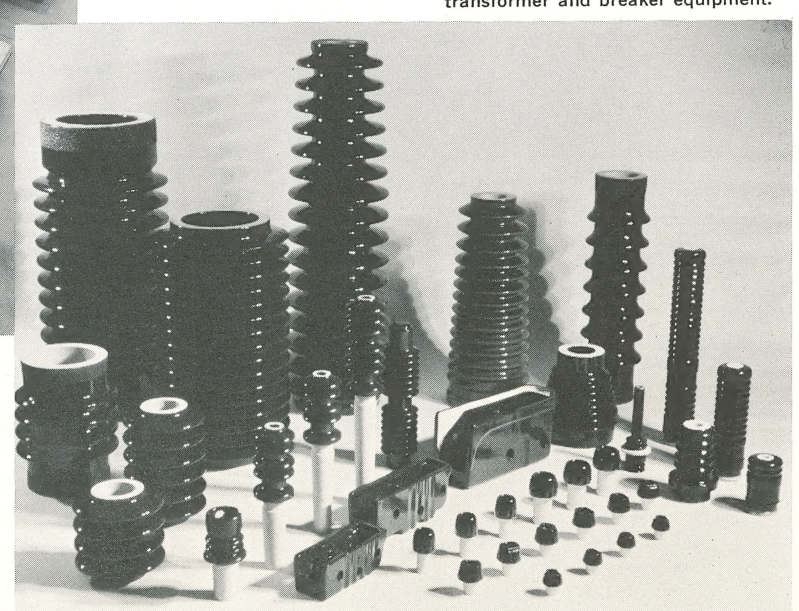


Many different varieties of small and medium size porcelain bushings.



Porcelain columns for air blast circuit breakers: (left to right) 138, 230, 345 and 500 kv.

1300 B.I.L. current transformer porcelains (foreground), long slender lightning arrester columns, and air blast breaker housings.



Panorama of apparatus porcelains including tiny stud bushings, fuse boxes cover bushings and porcelains for transformer and breaker equipment.

Introduction

In the manufacture of apparatus porcelain, there are certain characteristics and limitations inherent in ceramic processes. An understanding of these limitations and a careful consideration of their effects at the design stage, frequently permits the lowering of manufacturing costs, and a reduction of manufacturing losses with no sacrifice of performance in the final product.

The purpose of this bulletin is to provide the apparatus designer with information helpful to him in designing porcelain parts for his apparatus. It is also designed to assist those who buy porcelain to know more about it and to understand the problems in its manufacture.

For additional engineering information on apparatus porcelains and data on other LOCKE* insulators, call your Insulator Department sales representative, or write to Insulator Department, General Electric Company, 2525 Insulator Drive, Baltimore, Maryland 21230.

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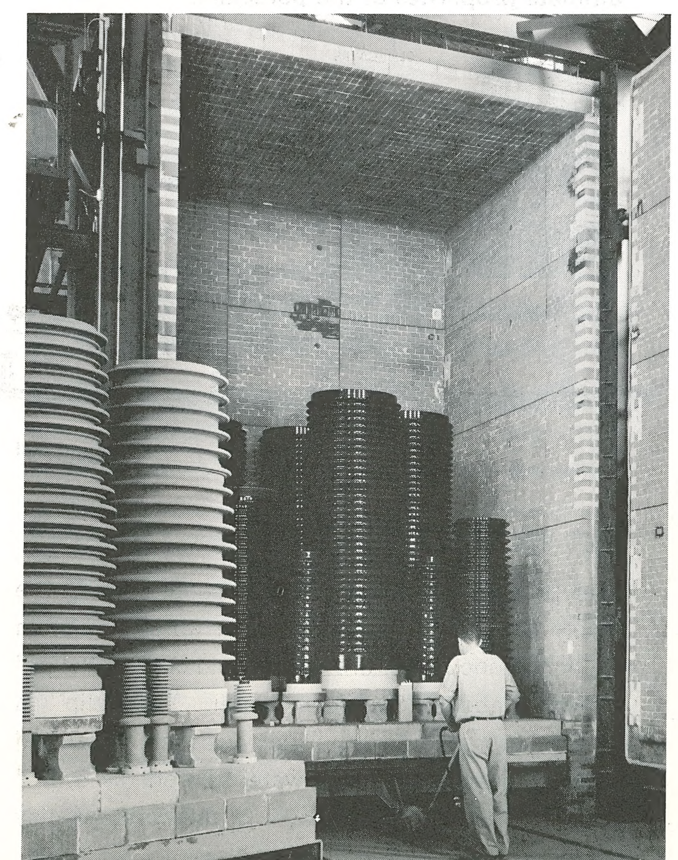


Frank Cermak EHV Kiln is completely automatic and is believed to be the largest and most sophisticated periodic kiln in the world.

Porcelain

Porcelain, one of the oldest known materials to man, is still one of the most essential materials required in the transmission and distribution of electrical energy. It is a hard, brittle vitrified ceramic.

Vitrification is a thermochemical process where the various ceramic materials of a composition are joined by a glassy bond. This glassy "matrix" surrounds the particles of clay and silica resulting in a completely dense, non-porous, mechanically and electrically strong ceramic.

High voltage electrical porcelain contains approximately 50 percent clay, 25 percent flint (or quartz) and 25 percent feldspar.

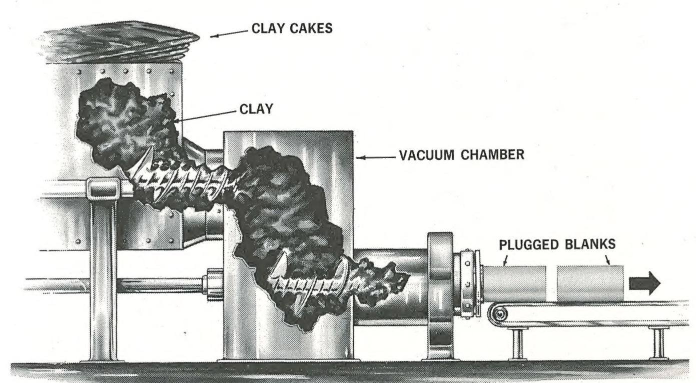
Flint, the silicate used in porcelain, is a finely ground quartzite. It is non-plastic in the unfired state. During firing flint reacts chemically with feldspar and forms a glassy plastic mass, which ties the composition together in a dense, non-porous structure. The larger grains of flint (silica) are only slightly reactive, retain their identity, and serve as a skeleton for the structure.

Feldspar contains the alkali and alumina required in a ceramic mix. These ingredients in the feldspar are the chief glass forming agents, and during firing, melt at lower temperatures than the other constituents of the mix. Feldspar reacts with some of the flint to form a bonding agent.

Ball Clay, sedimentary in nature, contains fine particles of organic material. It provides needed plasticity during the pugging operation and strength to the dry clay as it is contoured. During firing the carbons of the ball clay are oxidized, and the resulting ash serves as part of the matrix for the fired porcelain.

China Clay (or kaolin) is also sedimentary in nature, but is free of organic particles and coarser than ball clay. It is used with the ball clay to provide, to a lesser degree, the same properties of the ball clay.

Other Materials, such as talc and alumina, may be substituted for flint and clay in the manufacturing of special porcelains. These materials change the ultimate properties of the porcelain.



Extrusion Mill

WET PROCESS PORCELAIN

Wet process porcelain is prepared by mixing the finely ground raw materials with water to obtain an homogenous mixture. The liquid clay, or "slip," contains about 25 percent water. The "slip" is filtered of magnetic impurities and then dewatered in filter presses reducing water content by 6 or 7 percent. The "plastic clay" in the form of clay cakes is then ready for forming.

Pugging and Drying. Clay cakes are fed into an extrusion or "pug" mill which shreds the clay, moves it through a vacuum chamber to eliminate voids, and extrudes it through an orifice by means of an auger. A mandrel mounted on the auger shaft produces the internal diameter of the tubular blank. The blank is then carefully dried until there is about 5 percent moisture remaining.

Finishing. Finishing or contouring of an apparatus porcelain is similar to the method used for wood turning on a lathe. The quantity and size of the piece required determine the kind of lathe to shape a specific design: a single spindle lathe where a single point cutter follows a profile, multi-spindle type which cuts several pieces at one time, or a plunge cutter which shapes the piece in one quick step. All of the above methods duplicate an engineering drawing with the use of metal profiles and power-activated followers.

Glazing. After additional drying, the piece is ready for application of glaze, a specially compounded mixture of glass producing elements. Glaze is applied by spraying or dipping.

Firing. The finished glazed piece is then fired at 2300 degrees Fahrenheit, converting the crystalline phase into a completely vitrified mineralogical structure. The fired porcelain in its hard, stone-like condition, is ready for final finishing and assembly.

Final Finishing, Assembly and Tests. Frequently, the applications for porcelains require smoother bearing surfaces or closer dimensional tolerances than can be achieved through normal manufacturing operations, so grinding or final finishing is necessary. Assembly of the porcelain with hardware, and routine and special acceptance tests are the final steps in the manufacturing cycle.

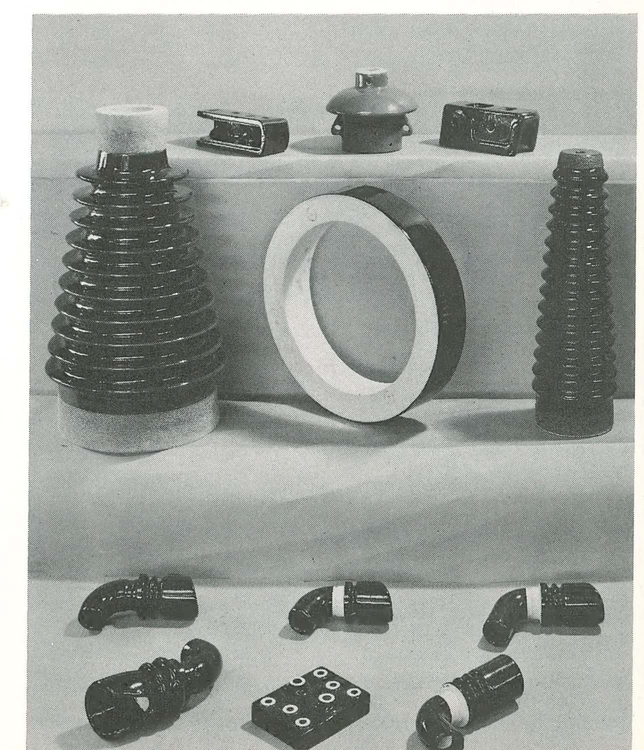
CASTING PORCELAIN

Designs, because of shape, which cannot be contoured by rotation on a lathe, are formed by a casting process. Plaster molds are filled with liquid clay. The plaster draws water from the clay, causing it to set and allowing the mold to be removed. The clay is then in a state dry enough for contouring on a profile lathe, and follows the same manufacturing steps described in the wet process method.

DRY PROCESS PORCELAIN

Porcelains for special low voltage applications are made by the dry process method. In this process, a drier mixture of clay and water is pressed in a steel mold, producing a specific shape in one step. Closer dimensional control is possible by the dry type manufacturing method, but this process cannot produce the electrical and mechanical properties inherent in wet process porcelains.

Shapes made by casting process.



Characteristics

Ultimate electrical and mechanical strength requirements for a specific piece of porcelain will determine the ceramic body composition, standard or high strength, to be used in the manufacture of the piece. Figure 1 gives the general characteristics of the two types of wet process porcelain.

CHARACTERISTICS

	WET PROCESS PORCELAIN Standard Strength	High Strength
Physical Properties		
Specific Gravity	2.38	2.77
Density (lbs. per cubic inch)	0.086	0.103
Hardness (Moh's scale) body	7.0	7.0
Hardness (Moh's scale) glaze	6.5	6.5
Water Absorption (%)	0	0
Total Shrinkage, % dry basis	13.1	14.2
Mechanical Properties		
1 Modulus of rupture, unglazed (lbs./in^2)	11000	18000
1 Modulus of rupture, glazed (lbs./in^2)	15000	25000
Compressive strength (lbs./in^2)	50000	75000
Tensile strength, unglazed (lbs./in^2)	6000	8500
Tensile strength, glazed (lbs./in^2)	7000	9500
2 Impact strength, unglazed (ft. lbs.)	0.7	1.0
2 Impact strength, glazed (ft. lbs.)	0.8	1.2
Modulus of elasticity (lbs./in^2)	10x10^6	14x10^6
Electrical Properties		
3 Dielectric strength (volts/mil)	200	200
Power Factor	0.0085	0.0063
4 Loss Factor	0.0476	0.0403
A.W.S. L — classification	L-2	L-2
Dielectric constant (k)	5.6	6.4
5 Volume resistivity (megohm/in^3)	4x10^6	4x10^6
6 t_e value (°C)	300	300
Thermal Properties		
Resistance to thermal shock	Good	Good
Linear coefficient of thermal expansion x 10^6 (0°-600°C)	5.94	6.8
Thermal conductivity (cal/cm^2/cm/sec/°C)	0.0034	0.0047

Notes:

1. Test bars 0.75″ diameter, span 5″.
2. Standard Charpy Impact Test — test bars 0.75 diameter, span 4″.
3. Specimens approximately 250 mils thick.
4. After soaking in distilled water for 48 hours at room temperature tested at 1.0 mc per AWS C-75.1—JAN—I-10.
5. At 10 volts per mil and 77°F.
6. Temperature at which centimeter cube has resistance of 1 megohm.

Figure 1

MECHANICAL AND ELECTRICAL CHARACTERISTICS

The characteristics shown are results from tests made on standard test specimens and should be used only for a direct comparison of materials. Like all other materials, the characteristics of porcelain developed in specific geometric configurations vary widely. Insulator designs, therefore, must be based to a great extent upon empirical data and judgment. There are, however, general trends in the relation of loading and size. These trends are illustrated in the curves in Figures 2 through 5.

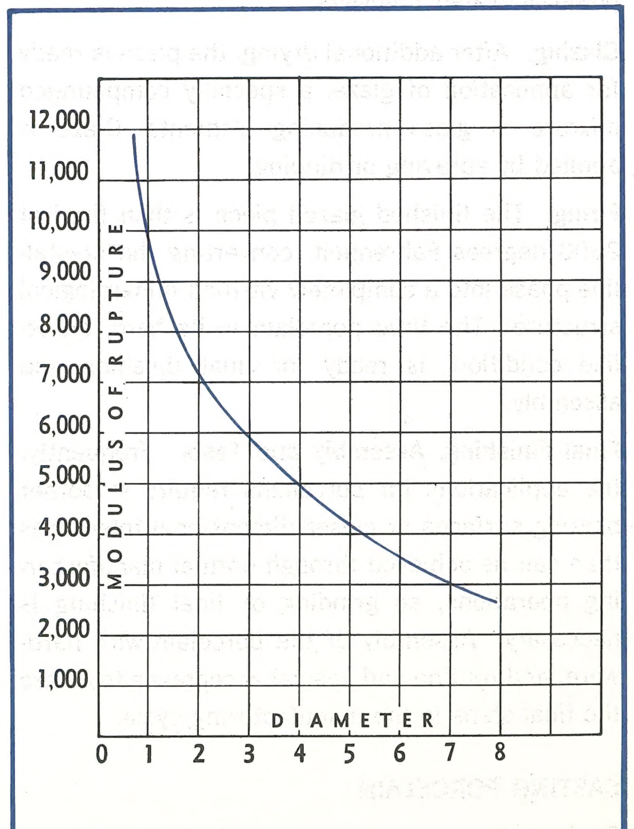


Figure 2 — Typical Curve Showing Relation of Modulus of Rupture to Diameter

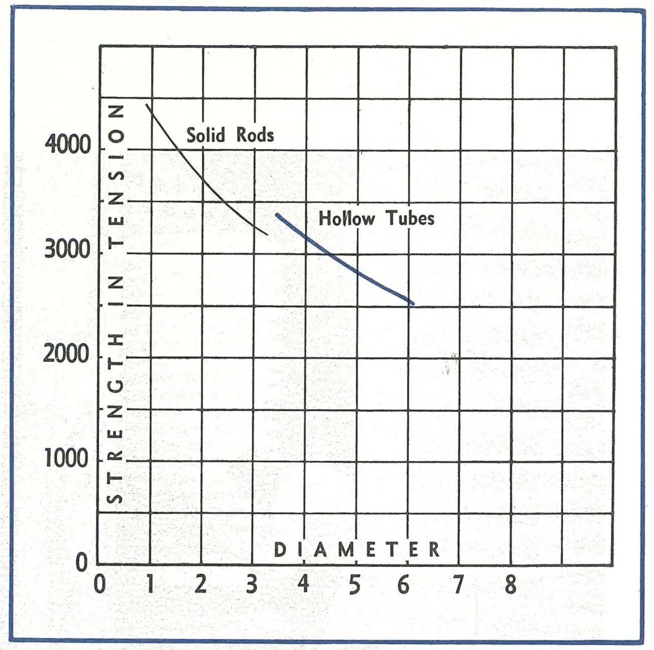


Figure 3 — Typical Curve Showing Relation of Tensile Strength to Diameter

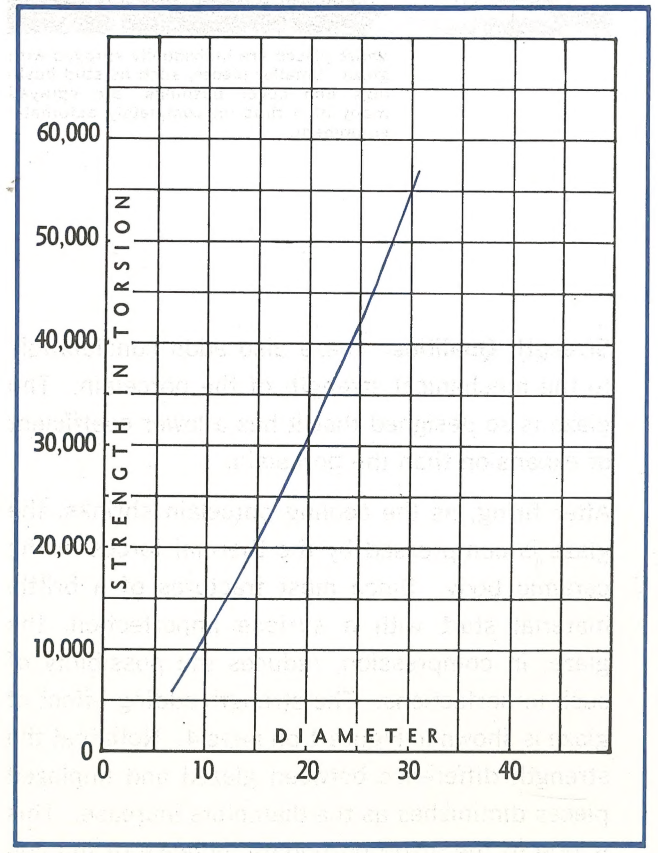


Figure 4 — Typical Curve Showing Relation of Torsional Strength to Area of Sanded Surface in Switch and Bus Insulators

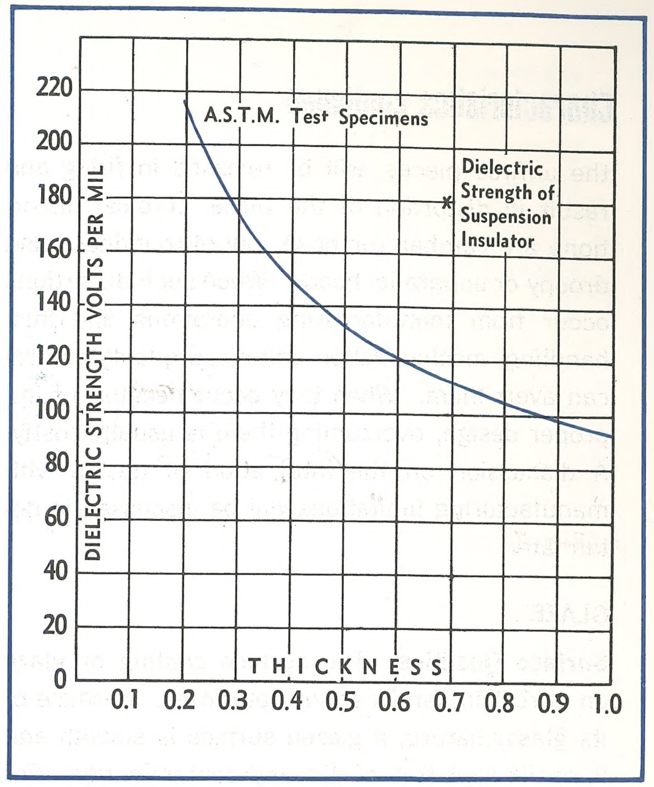


Figure 5 — Typical Curve Showing Relation of Dielectric Strength to Thickness

RESIDUAL STRESSES

In the manufacture of porcelain parts, undetectable forming or drying stresses may be present in the unfired blank from which the final shape is made. These stresses are quite similar to those present in metal parts. **Forming** stresses can be compared to those found in forged or rolled parts. **Drying** stresses are similar to those encountered in metal castings not uniformly cooled.

Many such stresses in metal parts can be relieved by annealing before machining. If this is done, very little distortion, if any, occurs during the finishing or subsequent heat treatments. Porcelain, unfortunately, cannot be stress annealed before machining or finishing. Stresses resulting from manufacturing operations, or mishandling of

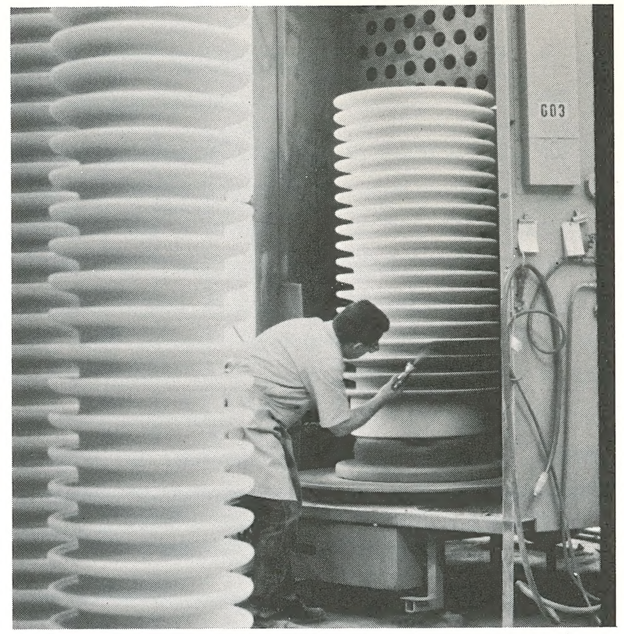
Characteristics continued

the unfired pieces, will be released in firing and result in distortion of the piece. Typical distortions are camber (or bow), out-of-roundness and droopy or unparallel hoods. When such distortions occur from manufacturing operations and mishandling, mechanization and close quality control can avert them. When they occur because of improper design, overcoming them is usually costly. A discussion on the integration of design with manufacturing limitations will be discussed in detail later.

GLAZE

Surface Qualities. The surface coating or glaze on porcelain serves several purposes. Because of its glassy nature, a glazed surface is smooth and is easily kept free of dirt and contamination. For example, dust accumulated in storage or in service will not adhere to the same degree on a glazed surface as to an unglazed or bare porcelain surface. Glaze also adds attractive color to the porcelain.

Visual inspection of dry blanks in one of many large automatic periodic driers.



Large pieces are individually sprayed with glaze. Smaller pieces, such as stud bushings and cover bushings, are sprayed many at a time on completely automatic equipment.

Strength Qualities. Glaze also adds considerably to the mechanical strength of the porcelain. The glaze is so designed that it has a lower coefficient of expansion than the porcelain.

After firing, as the cooling porcelain shrinks, the glaze is compressed by the thermal forces in the ceramic body. Since most fractures of a brittle material start with a surface imperfection, the glaze, in compression, reduces the possibility of such imperfections. The strength-adding effect of glaze is shown in Figure 1 on page 4. Note that the strength difference between glazed and unglazed pieces diminishes as the diameters increase. This is due to the disproportionate increase of the volume of porcelain to the area of glaze with the increase in diameter.

Design Considerations

TOLERANCES

Porcelain, as all other materials, has its own peculiar characteristics, imposing limitations on the design and application of porcelain parts. The dimensional fidelity of porcelain that can normally be maintained, without extra cost, is ±3 percent on any dimension. Shrinkage, which is approximately 12.5 percent during the entire manufacturing cycle, is the largest contributing factor to the expected dimensional variations. Figure 6 will give you some idea of the change that takes place during the drying of the pugged blank and in the firing of the finished piece.

Variations in the complex chemical structure of the raw materials may cause a dimensional deviation of ± 1.5 percent. Particle orientation (influenced by design) during extrusion and casting also contributes to unpredictable variations.

Abnormal tolerances can often be maintained to a higher degree of dimensional exactness at increased cost. The sketches in Figure 7 show a breakdown of various degrees of maintaining

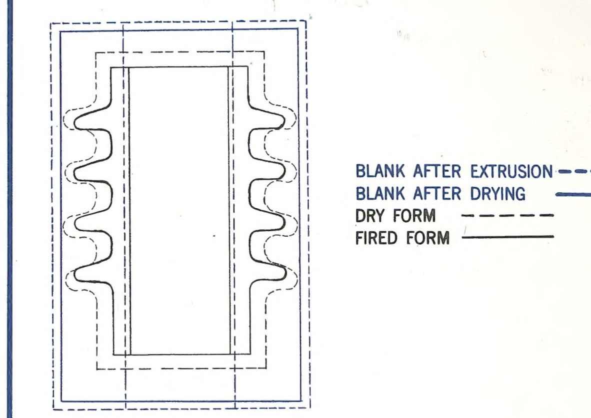


Figure 6

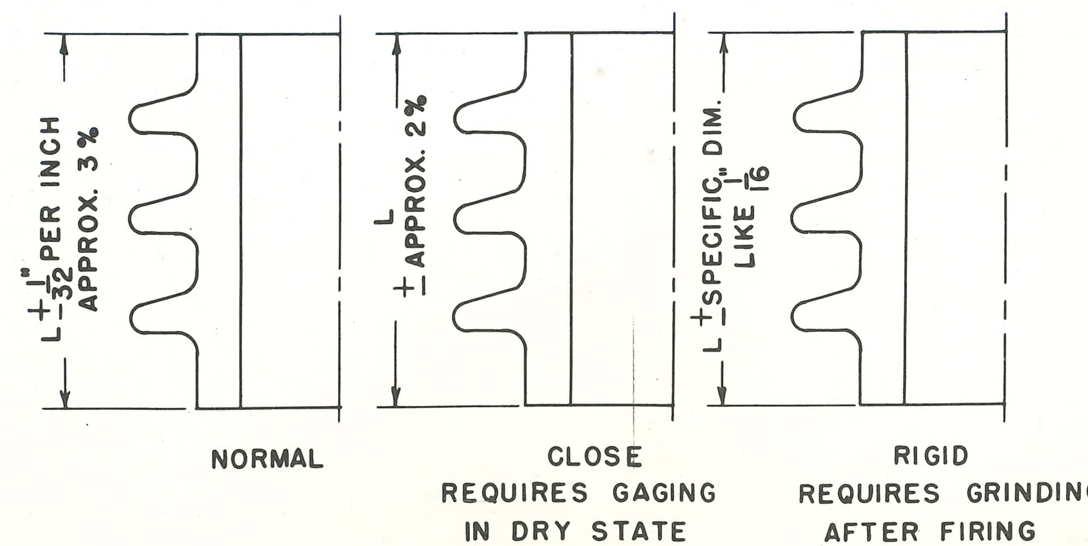


Figure 7

Design Considerations continued

dimensional fidelity. It is impractical, of course, from the designer's viewpoint, to adhere to the normal ±3 percent tolerance on large dimensions. Due to improved extrusion controls and closer finishing tolerances in the dry state, closer limits can be maintained and are shown in the sliding scale in Figure 8.

GROUND SURFACES

Porcelain surfaces can be ground with carborundum or diamond wheels. End surfaces are usually ground to maintain length tolerance, create square or parallel surfaces, or produce a satisfactory gasket seat. Precise grinding can assure minimum roughness and produce flatness (both circumferential and radial), and perpendicularity and parallelism. The desire for precision should be evaluated as it relates to added cost. Frequently selection of a different gasket to permit less precise grinding can afford a reduction in the cost of the piece.

Roughness measurements can be made and expressed in several ways. (See Figure 9.) The AVERAGE value of roughness is the average deviation from a center line on a profile contour of the surface. The AVERAGE PEAK-TO-VALLEY value is the average height of irregularities from peaks to valleys.

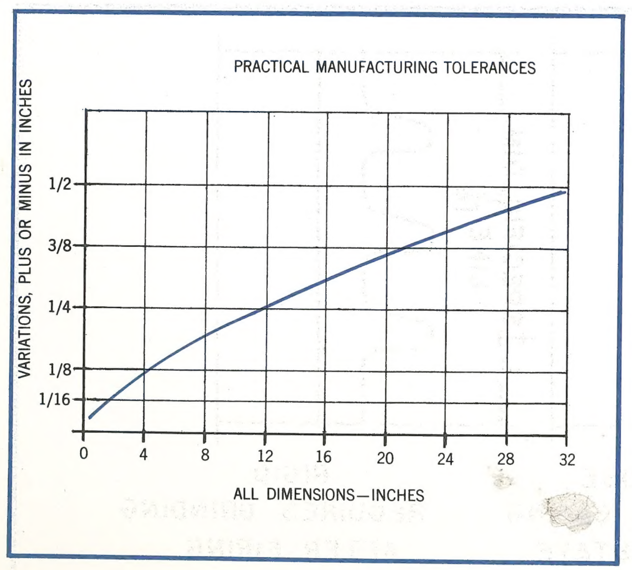


Figure 8

Surface finishes of 125 are normally satisfactory for adequate gasket sealing. Finishes of 63 or lower are obtainable, but at extra cost, and should be specified only when necessary. Application of a porcelain part in an assembly should never place the porcelain in direct contact with a metal part. A cushion in the form of a gasket, washer or neat cement, will compensate for small variations and eliminate stress concentrations.

ROUGHNESS (MICROINCHES)		A.S.A. FINISH SYMBOL
AVERAGE	AVERAGE PEAK-TO-VALLEY	
32	118	32
63	220	63
125	455	125
250	875	250
500	1750	500

Figure 9

Since sharp edges are easily chipped, all ground edges should be chamfered to prevent this kind of damage. Chamfering should be from 1/32″ to 1/8″. This dimension should be as large as is practical to ensure against chipping at the internal diameter breakthrough. However, unusually large chamfers reduce the effective gasket area. A guide for a proper relationship between the gasket surface and wall thickness is tabulated in Figure 10.

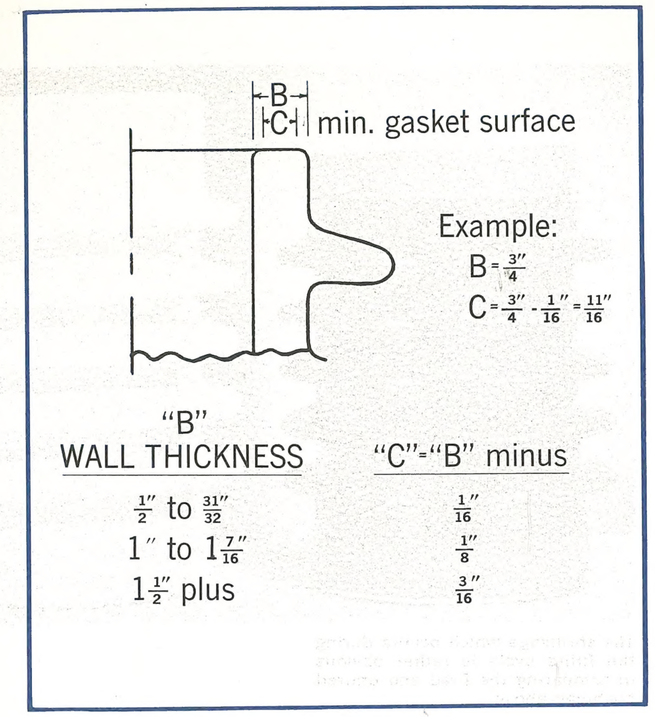
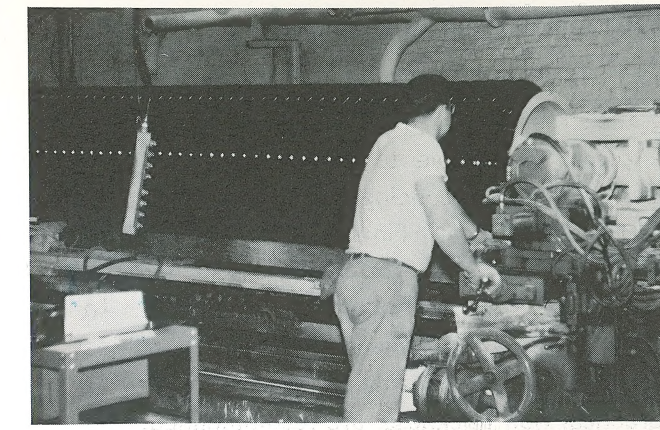


Figure 10

In order to adhere to very close tolerances, areas other than end surfaces can be ground but grinding must be done on special equipment. This increases both cost and manufacturing time. Some of these special grindings are shown in the sketches in Figure 11.

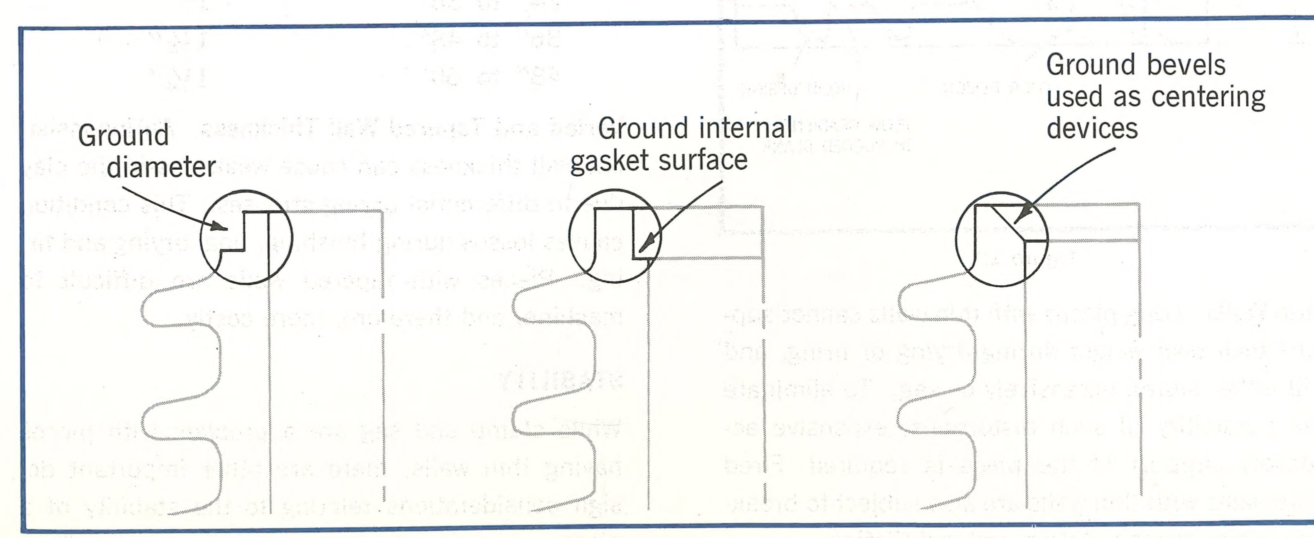


153 inch long porcelain for a current transformer is precisely ground by a large diamond wheel.

WALL THICKNESS

Thick Walls. An excessively thick wall of a pugged blank required to produce a desired design can affect the quality of the piece. As this wall thickness is increased, the drying process becomes more complex and time consuming. Drying must take place from the center outward to minimize residual drying stresses, and so closely controlled conditions must be maintained throughout the drying cycle.

The pugging (or extruding) process causes flow and density gradients across the wall, which become more apparent with increased thickness.



Design Considerations continued

(See Figure 12.) During drying, finishing, and firing, the stresses caused by these gradients, render the piece susceptible to fractures along these lines. This loss-producing factor will naturally affect the final cost. Finished pieces with thick walls require a longer firing cycle for thorough vitrification. This, too, incurs additional cost. To avoid this extra cost, the following relationships between outside and inside diameters, to arrive at a practical wall thickness, are recommended:

Small Pieces

up to 4″ O.D.	Min. I.D. — 1″
4″ to 6″ O.D.	Min. I.D. — 1½″
6″ to 8″ O.D.	Min. I.D. — 2″

Large Pieces

Max. O.D. less Min. I.D. — 12″ Max.
— 5″ Min.

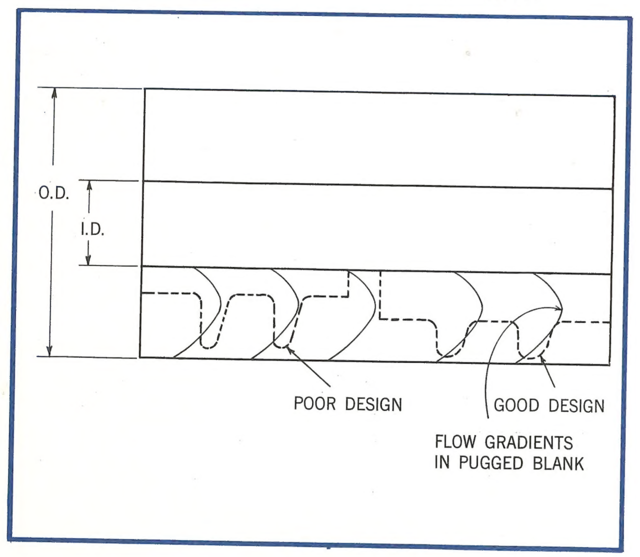
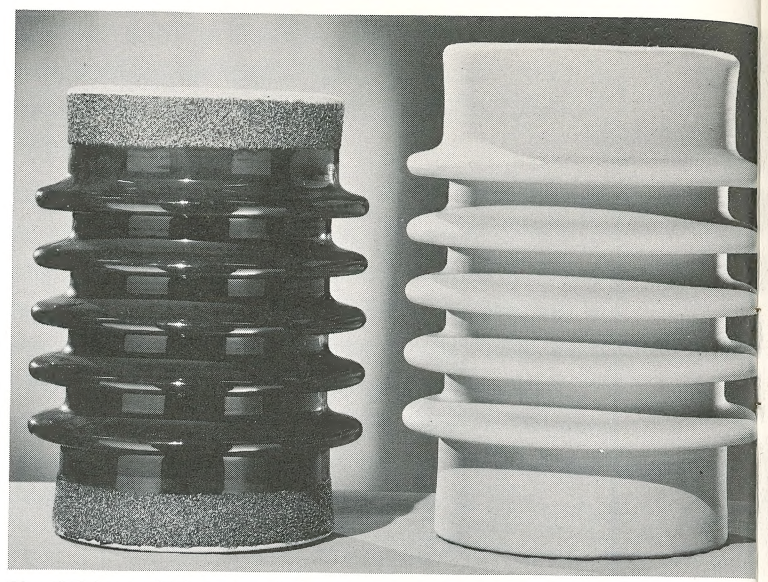


Figure 12

Thin Walls. Long pieces with thin walls cannot support their own weight during drying or firing, and will either slump excessively or sag. To eliminate the possibility of such distortions, expensive accessory support of the piece is required. Fired porcelains with thin walls are also subject to breakage during transportation and installation.



The shrinkage which occurs during the firing cycle is rather obvious in comparing the fired and unfired bushings above.

Insurance against premium costs can be accomplished by using the following suggested good design practices:

Length	Wall Thickness
up to 24″	⅞″ Min.
	2″ Max.
24″ to 36″	1″
36″ to 48″	1⅛″
48″ to 60″	1¼″

Varied and Tapered Wall Thickness. An inconsistent wall thickness can cause weakness in the clay due to differential drying stresses. This condition causes losses during finishing, final drying and firing. Pieces with tapered walls are difficult to machine, and therefore, more costly.

STABILITY

While slump and sag are a problem with pieces having thin walls, there are other important design considerations relating to the stability of a piece.

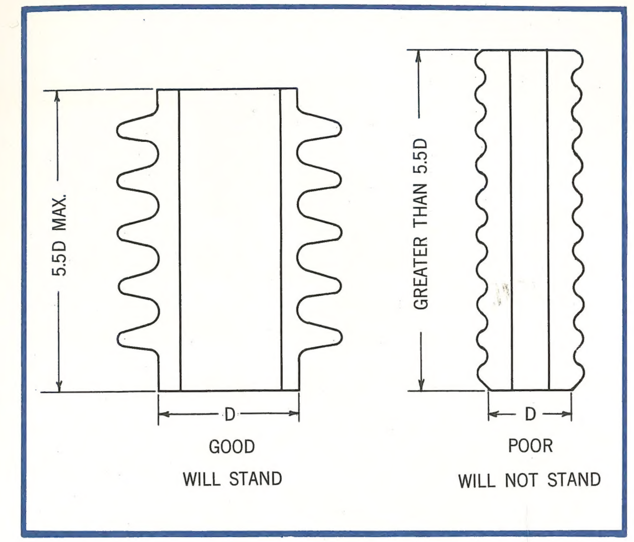


Figure 13

One is proper relationship between the length of the piece and the outside diameter. Again, if this is not the case, a supporting device is required and, of course, adds to the cost of the piece.

As shown in Figure 13, to achieve a self-supporting design, the length of the piece should not be more than 5.5 times the diameter D. Figure 14 illustrates various extra-cost devices to support an excessively slender design.

Long slender pieces are also subject to warpage which can occur during the drying and firing

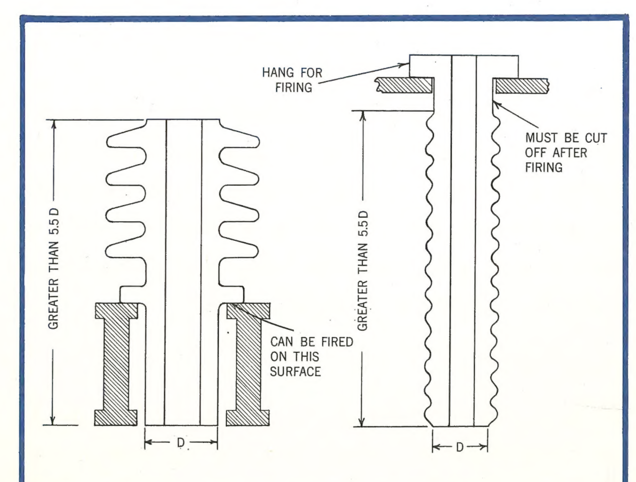
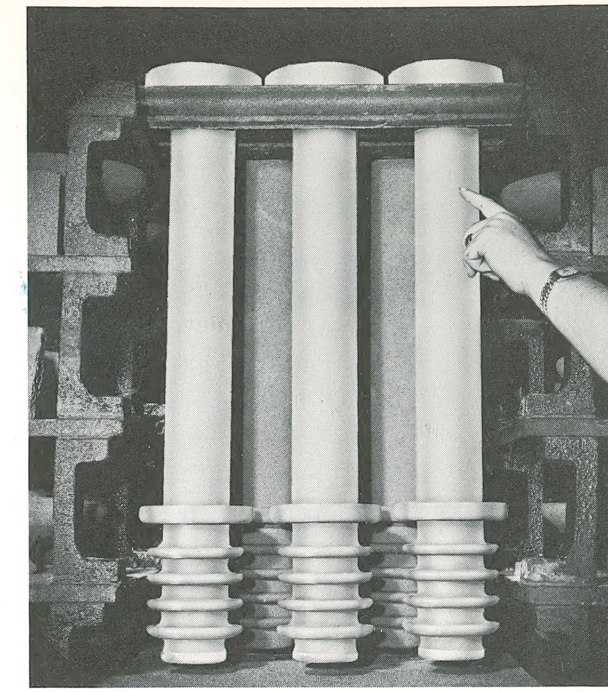


Figure 14



Slender pieces are hung in kiln car.

cycles. This kind of distortion takes the form of camber (or bow) and can be measured as shown in Figure 15.

In order to measure the warpage externally, the piece is rotated on a lathe and the total runout measured. The warpage is one-half of the total runout.

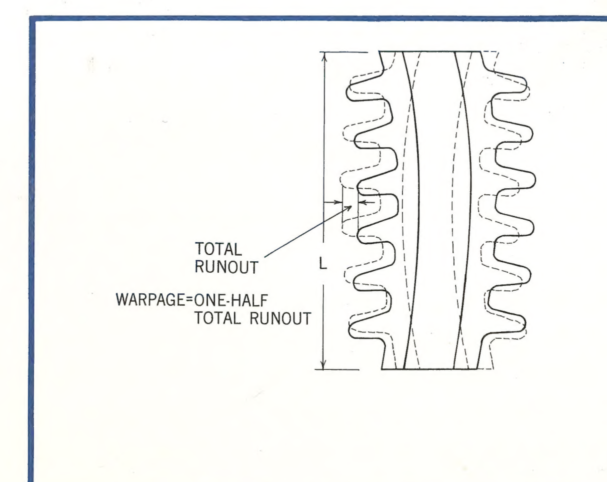


Figure 15

Design Considerations continued

Warpage is measured internally with a mandrel. The chart in Figure 16 lists recommended tolerances to indicate the maximum warpage that would normally be expected in a product such as porcelain.

RECOMMENDED TOLERANCES FOR WARPAGE OF BUSHING BORE BASED ON 1/8″ WARPAGE PER FOOT

		TEST ROD DIAMETER $^{+.000}_{-.002}$				
		LENGTH				
HOLE DIAMETER	HOLE TOLERANCE PLUS	0-8	8-12	12-18	18-24	24-30
1/2	1/32	7/16	3/8	5/16		
9/16	1/32	1/2	7/16	3/8		
5/8	1/32	9/16	1/2	7/16	3/8	
11/16	1/32	5/8	9/16	1/2	7/16	3/8
3/4	1/32	11/16	5/8	9/16	1/2	7/16
13/16	1/32	3/4	11/16	5/8	9/16	1/2
7/8	1/32	13/16	3/4	11/16	5/8	9/16
15/16	1/32	7/8	13/16	3/4	11/16	5/8
1	1/32	15/16	7/8	13/16	3/4	11/16
1-1/8	1/32	1-1/16	1	15/16	7/8	13/16
1-1/4	1/32	1-3/16	1-1/8	1-1/16	1	15/16
1-3/8	1/32	1-5/16	1-1/4	1-3/16	1-1/8	1-1/16
1-1/2	3/64	1-7/16	1-3/8	1-5/16	1-1/4	1-3/16
1-5/8	3/64	1-9/16	1-1/2	1-7/16	1-3/8	1-5/16
1-3/4	3/64	1-11/16	1-5/8	1-9/16	1-1/2	1-7/16
1-7/8	1/16	1-13/16	1-3/4	1-11/16	1-5/8	1-9/16
2	1/16	1-15/16	1-7/8	1-13/16	1-3/4	1-11/16

All dimensions in inches.

Figure 16

HOOD CONFIGURATION

In designing the configuration of the hoods (or petticoats) a proper relationship to wall thickness and clay flow characteristics must be considered. When the extension of the hood is held to a maximum of 2½″, a proper wall thickness of the pugged blank is assured, averting distortion of the hood from excessive weight. This kind of distortion can cause cracking during the firing cycle and produce a high level of losses.

The spacing between the hoods should not be less than 2¼″. This minimum spacing allows adequate clearance during the contouring operation. If the hood spacing is less than 2¼″, the electrical characteristics of the insulator, particularly under wet or contaminated conditions, could be adversely affected.

Radii in the hood design, if too small, become points of stress concentration and tend to weaken the porcelain. Small radii also make contouring on the lathe difficult and expensive. Internal radii in the hood configuration should not be less than ⅜″.

All of these fine points of hood design are illustrated in Figure 17.

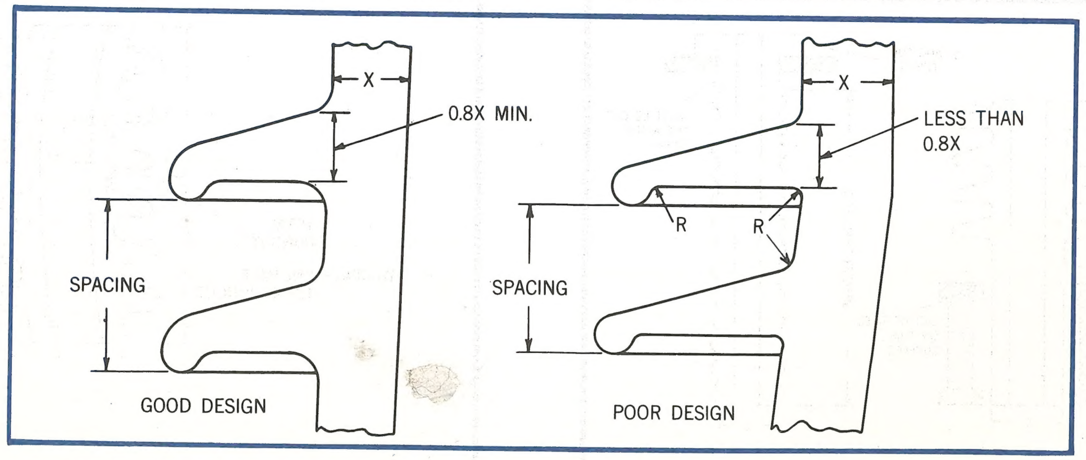


Figure 17

FILLETS AND ROUNDS

Fillets (internal radii) should not be less than ⅛″. (See Figure 18.) Smaller radii can be obtained but require additional finishing at extra cost. Since small radii in any material produce abrupt changes in cross section, they are points of stress concentration and thus points for potential cracks. Rounds R (external radii) should not be less than 1/16″, larger if possible.

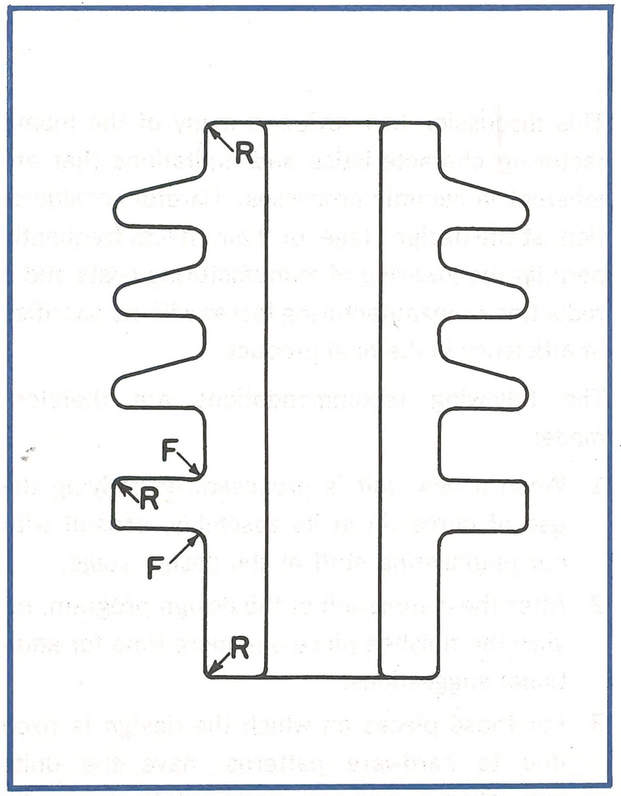
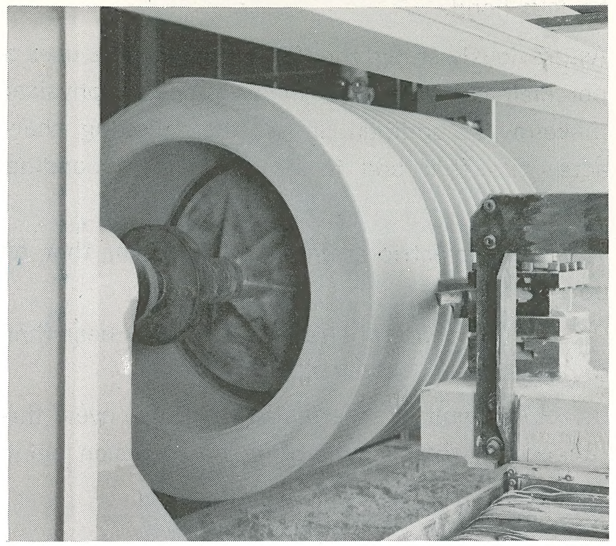


Figure 18

JOINING PORCELAIN PARTS

Frequently it is impractical to make extremely large porcelains in one single section, so a bonding together of smaller sections is the solution. General Electric's technique for this bonding is called the VitraWeld process.

A raw material composition was developed to give results in joining porcelain parts similar in many



An inside view of a large, completely automatic lathe contouring hoods on a large breaker bushing.

ways to those obtained in welding metal parts together. The joining materials melt during firing, thoroughly "wetting" the mated porcelain parts. While cooling the melted joint material solidifies. During solidification a large part of the melted material crystallizes, forming a porcelain-type material with crystal phases in a glassy matrix. Thus it becomes basically very much like the porcelain, also made up of crystal phases in a glassy matrix. The general analogy to welding is, of course, evident. In the welding operation the welding rod metal melts, and on cooling recrystallizes to a form very much the same as the parts being joined.

Another analogy might be made by considering the interface between the porcelain and the joining material as compared to that of the metal and welding material. In the case of the VitraWeld process there is reaction between the porcelain surface and the joining material which makes a very thin tight bonded interface between the two. In welding, surface melting of the metal part alloys

Design Considerations continued

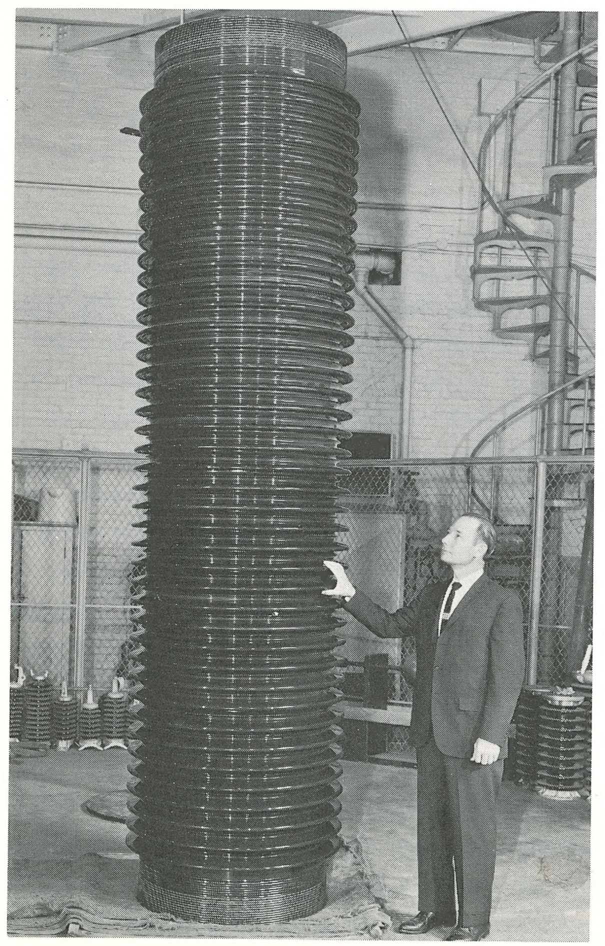
with the molten welding metal to form a tight continuous bond.

As previously stated the Vitra Weld process uses a porcelain-like material in its general physical makeup. In addition, it has the following characteristics that add to its value as a bonding material:

1. High dielectric strength — very near that of porcelain.

2. High mechanical strength, also very near that of porcelain.

3. Coefficient of thermal expansion over the range from room temperature up to fusion point closely matches that of porcelain.



500 kv air blast breaker porcelain made in four sections, joined together by the Vitra Weld process, and fired as one piece.

Summary

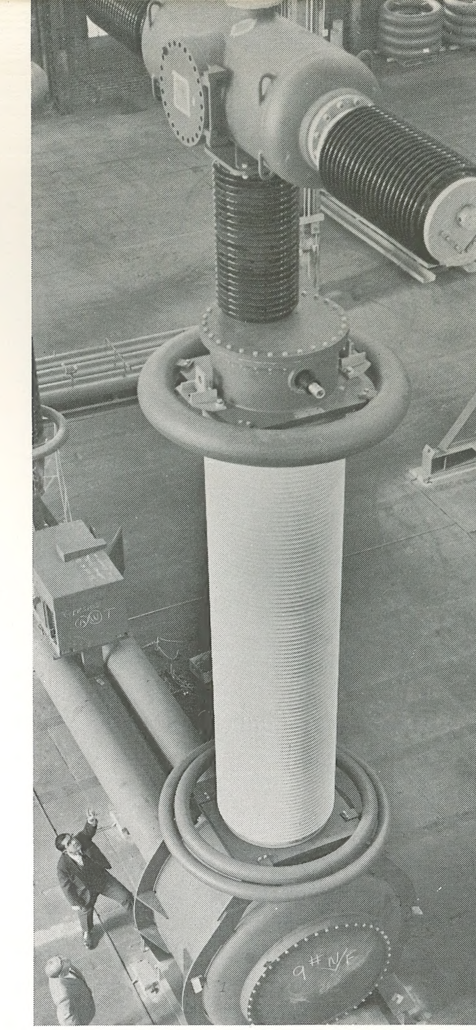
This discussion has reviewed many of the manufacturing characteristics and limitations that are inherent in ceramic processes. Careful consideration, at the design stage, of their effects frequently permits the lowering of manufacturing costs and a reduction of manufacturing losses with no sacrifice of efficiency in the final product.

The following recommendations are thefefore made:

1. When a new unit is proposed, embodying the use of porcelain in its assembly, consult with our engineering staff at the design stage.
2. After the completion of the design program, review the finished piece one more time for additional suggestions.
3. For those pieces on which the design is fixed due to hardware patterns, have the units rechecked by our engineering staff. It may be possible to make cost-reduction modifications without causing any changes in the hardware.

The industrial revolution is still continuing in the porcelain industry. Modern mechanization trends have made possible great simplications in manufacturing. Intensive quality control techniques have made possible a superior, quality LOCKE insulator. At General Electric, manufacturing innovation and assurance of quality offers the user a better product at a better price.

Apparatus Polymers - *tomorrow's insulators today*



One of three one-piece 180 inch GEPOL® polymer insulators on a General Electric 500 kv air blast circuit breaker.

GEPOL polymer insulators are also used as insulating elements on a new 230 kv vacuum fault interrupter made by the Hi-Voltage Equipment Division, Joslyn Mfg. and Supply Co.